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BUILDING INFORMATION MODELLING: AN INNOVATIVE WAY TO MANAGE RISK IN CONSTRUCTION PROJECTS

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Abstract

Background. Building Information Modelling (BIM) has been recently one of the most common issues discussed in publications related to innovative changes in the management of construction projects. The concept of BIM integrates all the activities related to the design, construction and operation into the ICT model developed and implemented within a communication platform. From the point of view of the project management theory and construction practice, the area of interest is integrated risk and change management based on BIM. Negative consequences such as delays and financial losses that are detrimental especially to public projects conducted by investors raise a question of whether and how implementation of principles of BIM in project management can improve management activities associated with risk in construction projects.

Research aims. This paper aims to gain insight into the current state of knowledge about risk and change management in construction projects in terms of BIM implementation, and to set the direction for further research as well as to determine further research objectives related to this issue.

Methodology. The arguments presented in this paper are based on the analysis of reference literature.

Key findings: Risk is an issue in the concept of BIM that still needs to be systematized. It is necessary to develop an optimal way to integrate procedures, methods and techniques of risk management with other management actions within BIM. Change is perceived as one of the major risk factors and therefore the inclusion of change management processes into this system also requires the establishment of standards and methodical approach within BIM. Further research in this area should include past experience in the implementation of BIM in construction projects, the presence of risk-related procedures in this process and conditions of effective integration of management actions. From a practical point of view, it is also necessary to explore the willingness of entrepreneurs and investors to implement BIM, understood as a platform for communication, risk and change management as well as an optimal method for a systematized implementation of this process.

Keywords: risk management, construction projects, building information modelling

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INTRODUCTION

Any construction project is a multistep and interdisciplinary process. Its implementation involves a large team of specialists in various fields representing investors, architects, contractors and construction supervisors. Each of the parties in this process have their own goals and pursue their own strategy to achieve them. Good communication at each stage of the project life cycle is essential for the proper coordination of cooperation between participants in each project (Elmualim & Gilder, 2013, p. 3). It has also important implications for risk management, which in construction projects is subject to particularly high impact of the human factor (Loosemore & McCarthy, 2008; Zou & Zhang 2009, p. 72). Participation of many parties enhances the diversity and number of risk factors and the interaction between them (Drzewiecka & Pasławski, 2011, p. 475). In traditional building projects, various participants carry out their tasks separately. After ordering design documentation, the investor often does not participate actively in the further process, relying on the professional knowledge and experience of the architect. The investor usually does not take active part in the project implementation. He or she is commonly represented by a construction supervision inspector. The investor does not contribute to daily decisions related to the project implementation. In this way, the ongoing flow of information between the parties is very limited. Thus, each participant of the project focuses on their own goals and problems. Risk is identified and analysed by them separately, making it difficult to manage it in an integrated way. This piecemeal approach and a lack of coordinated decisions concerning the entire project leads to low efficiency of risk management (Elmualim & Gilder, 2013, p. 2). Even if individual participants use advanced techniques and tools of risk management, in the absence of effective communication the use of the most modern instruments of risk analysis and planning does not produce expected results. It is people that create a project team, take decisions and actions, and therefore one of the priority management functions is to communicate decisions transparently concerning risk and risk management to all participants in the construction project (Jobling *et al.*, 2006, p. 238). It is clear both from the literature and from the practical experience of the author that a lack of communication and the resulting lack of a common, mutual understanding of the project, its objectives and its course are among the greatest threats to the success of the project (Loosemore & McCarthy, 2008; Tah & Carr, 2001).

Azhar, Hein and Sketo (2012) claim that the implementation of Building Information Modelling (BIM) significantly improves building performance and predictability of outcomes. Therefore the question arises whether and how implementation of the principles of BIM in project management can improve management activities associated with risk in these projects. The aim of this article is to present the results of a review of recent publications on the management of building projects in terms of Building Information Modelling (BIM) and with respect to the issue discussed by the author, i.e. the use of BIM for the integration of communication and risk management processes in construction projects. This will set the direction for further author's research.

To achieve this goal, an extensive review of scientific and professional publications concerning BIM and risk management issued in 2000–2014 was made. The review involved traditional publications and those available in databases of journals and online libraries (Science Direct, Springer, Elsevier, ASCE) as well as conference materials published on the Internet. The research focused mainly on articles published in academic journals specialised in project management in construction industry and risk management. The review process took place between December 2014 and May 2015. The results of the initial search by the keywords "BIM and risk management" included more than 90 publications, among which 32 were analysed. They were selected for compliance with the review objective. To be included in the final list papers had to meet the following criteria: relate to BIM use in management of construction project and provide a discussion on risk in BIM projects simultaneously. The results of the review are described in this article.

REVIEW

Integrated risk management in construction projects

According to the model of risk management proposed by the UK Treasury, the core of the process is communication and learning, understood as a collection of experiences and good practices. Around this core, there are ongoing activities related to risk identification, analysis and evaluation as well as risk response planning and monitoring. Different types of risk that occur in the project interact with each other and require complex decision-making and management activities (HM Treasury UK, 2004 p. 13). Project management methods that have been known and practiced for many years, assume that good communication is one of the key elements of an effective risk management system (Loosemore & McCarthy, 2008; Tomanek & Juricek, 2015). The quality of communication and consultation with project stakeholders has a direct impact on the effectiveness of risk management (Teixeira *et al.*, 2011, p. 24).

The issue of risk management in projects have been extensively described. While the reference literature presents several definitions and concepts concerning this subject, there is still no systematic approach to risk issues in a practice of construction industry and risk analysis and management depend mainly on intuition, judgement and experience (Abdou, Alzarooni, & Lewis, 2004, p. 146; Taroun, 2014, p. 109). The construction industry is fraught with much greater risk than other areas of industrial activity, which results from the specific nature of building projects (Mills, 2001, p. 245). They are characterized by:

- the unique character of each construction work;
- frequent significant interference with the natural environment and at the same time a strong influence of climatic, topographical and hydrogeological conditions;
- a long period of investment preparation and implementation;
- a long life span and high capital demand;
- the complexity and diversity of works;
- the specifics of logistics (frequent changes in suppliers, subcontractors), the need to move resources;
- big workload and energy consumption;
- the need for close cooperation between participants in the process (Grzyl, 2011, p. 1320).

This is connected with a significant number and variety of risk factors that require a comprehensive assessment and response planning. These factors can be classified with regard to the effect of risk on the main parameters of the construction project, such as lead time, cost and quality. Risk can also be identified in subsequent phases of the project life cycle (Zou & Zhang, 2009). Texeira *et al.* (2011) suggest that risk in construction projects should be considered in the three categories:

- general risk;
- specific organizational risk;
- specific technical risk.

The first category includes risks associated with the economic and legal context of the project. Factors that are taken into account in this regard include strict rules and disorderly changes in construction law and a number of other regulations relating to the construction process. The category of specific organizational risk includes factors related to a lack of the investor's cooperation, insufficient experience and a lack of competence of the architect, contractor and representatives of the investment supervision, financial difficulties of the contractor or subcontractors, the absence or illegibility of project management procedures, unclear provisions in contract documentation or impaired communication between participants in the investment and construction process.

The third category of specific technical risk includes the following risk factors:

- those related to weather conditions (low temperatures, strong winds, heavy rainfall);
- those that may occur on the construction site, for example, incomplete data on soil and water conditions at the design stage generating geotechnical risk, and incomplete information about underground objects resulting in collisions during construction works;
- limited availability of manpower with the required qualifications and experience;
- disruption of communication between construction teams of the contractor and subcontractors;
- difficulties related to the supply of materials that meet the requirements of the project and contract documentation, susceptibility of materials to damage during transport and storage;
- design errors (Teixeira *et al.*, 2011, pp. 66–67).

Having regard to the efficiency and effectiveness of the construction project, this rich collection of risk factors needs to be managed in a holistic way (Rudnicki & Słobosz, 2014, p. 6). Lam (2003) argues that the effectiveness of risk management instruments, procedures and systems can be achieved if the organization has a strong culture of risk management. The concept of enterprise risk management (ERM) assumes a combination of management actions in the area of risk with overall business objectives. Under this approach, individual risk factors should be viewed through the prism of their interactions, as links of a value chain (Folga, Redliński & Słobosz, 2014, p. 15). Using this perspective, the company avoids the most common errors in risk management:

- risk identification and assessment in separate organizational units, in processes occurring in isolation from the other activities of the enterprise;
- fragmented risk management activities resulting from this approach and conducted in individual departments (accounting, managerial auditing, purchasing department, etc.) rather than across the enterprise;
- leaving risk without the owner, i.e., the person directly responsible for planning and taking action in the event of risk materialisation;
- a lack of a common language for risk analysis and assessment across the enterprise;
- a lack of communication between individuals and organizational units involved in the management of successive risk factors;
- a narrow understanding of risk management methods, including avoidance or insurance (Rudnicki & Słobosz, 2014, p. 6).

The introduction of integrated risk management across the construction company can bring a similar result. A survey carried out by Abdou, Alzarooni & Lewis (2004) among construction companies indicates that risk management in construction projects is performed mainly *ad hoc*, based on "intuition, subjective assessment and experience" and still remains an area that needs considerable support and implementation of modern tools and methods. These include methods such as keeping a risk register, process mapping, sensitivity analysis, decision analysis, simulation methods, or probabilistic and statistical methods. Although they have been described in the literature and tested in practice, they are of little use in the implementation of investment and construction projects (Tah & Carr, 2001; Abderisak & Lindahl, 2015, p. 553). Research results indicate that this is primarily due to the fact that participants in the investment and construction process lack expertise in risk management, do not understand the risk analysis and have mental barriers (Abdou, Alzarooni & Lewis, 2004, p. 141). Jobling, Merna and Smith (2006) argued that a process of adopting risk management depends very much on the people responsible for maintaining, performing and developing management guidelines and procedures in a company that is the managers themselves. "Because of this, many companies benefit from having innovative managers who encourage risk management, but many suffer from management, which is averse to it" (Jobling, Merna & Smith, 2006, p. 238).

Integrating risk and change management

The major problems that are associated with the necessity of comprehensive risk assessment and response planning in the event of risk materialization are caused by changes in the construction process (Akram *et al.*, 2012; Kasprowicz, 2014). When introduced in the course of a construction project, they may significantly impede the implementation of initial assumptions concerning time, cost and basic parameters that determine the attainment of project objectives. Insufficient coordination of design work within individual sub-sectors, and design based on incomplete or outdated input data may require a number of changes in the implementation phase. It is essential to manage these changes and manage project risk in order to avoid exceeding schedules or cost of the project. Akram *et al.* (2012) highlight the key principles that should be taken into account in the process of change management:

- development and modification of intent should be considered an ongoing process, carried out at all stages of the project life cycle;
- design intent should be constantly reviewed, adapted to actual conditions in an innovative way, according to external and internal factors and for the benefit of the successful implementation of the project;
- a system of developing intent and introducing changes should be made at the earliest stage of the project;
- feedback from the client, the design and construction team, notes and comments of the property management staff and the end users make it possible to improve the quality of the process of developing intent in future projects.

The traditional way of communication between participants in the project is based on design documentation (two-dimensional drawings, documents describing the project, its implementation technology and projected costs) and contract documents signed by the parties. These documents, which form a set of enterprise data, are exchanged between participants in the process, but their information carrying capacity is limited. Building Information Modelling integrates information sets about a building structure and enables participants in the process, including the investor, to integrate into the entire life cycle of the project (Azhar, Hein & Sketo, 2012, p. 251).

Building information modelling as a concept of project management – state of the art

The number of articles and studies on BIM has grown rapidly in recent years. There have been many proposals to define BIM as a concept, a technology, a process, a method or a construction project management paradigm. In their systematic review of 180 publications on BIM, Volk, Stengel and Schultmann (2014) suggest two ways of perceiving and defining BIM. In narrow terms, it is understood as a tool – a digital building model itself in the sense of a central information management hub or repository and its model creation issues. In this article BIM shall be seen from a second, broader perspective that comprises interrelated functional, informational, technical and organisational issues (Volk, Stengel & Schultmann, 2014, p. 111). The essence of construction project management in accordance with the so-understood concept of BIM is to integrate information about the planned and then executed building structure in the form of a digital building model including data on architecture and design, and other information necessary for the implementation and operation of the constructed facility. The scope of the information contained in the model includes:

- geometric information about the proposed facility;
- structural information – results of design calculations, data on materials, construction technology and proposed installation;
- supplementary information generated during the preparation and subsequent implementation of the project concerning costs, schedules and resources, land development project and other construction management areas such as safety and health (Zima, 2013, pp. 79–80).

All the data that are now collected in the form of a model were previously scattered in sub-sector documentation. The essence is a building model developed by architects. It is then supplemented by sub-sector documentation. The design process is carried out in parallel with constantly refined tools. Designers from individual sub-sectors have permanent, simultaneous access to the model. The information contained therein is also available and transparent for all other participants in the construction process, from the stage of conceptualization and preparation of the investment through all subsequent stages of the project life cycle.

The concept of object modelling is not new and has been already implemented in other industrial sectors as product information modelling (Adamus, 2012, p. 14). It is now widely used in the construction industry in several countries such as Finland, the USA, Singapore and the United Kingdom (Kiviniemi *et al.*, 2008; Oakley, 2008; Wong *et al.*, 2010; Khosrowshahi & Arayici, 2012; Smith, 2014; Eadie *et al.*, 2015). In the Central and Southern Europe, interest in BIM has been rapidly increasing in recent years (Matějka & Tomek, 2014). Among the effects of BIM implementation, attention is paid primarily to economic benefits. An analysis of 32 major projects undertaken by the Stanford University Center for Integrated Facilities Engineering (CIFE) in 2007 identified the following effects of BIM application:

- up to 40% elimination of unbudgeted change;
- cost estimation accuracy within 3%;
- up to 80% reduction in time taken to generate a cost estimate;
- savings of up to 10% of the contract value through clash detection;
- up to 7% reduction in project time (Azhar, Hein & Sketo, 2012, p. 3).

Other benefits associated with the implementation of BIM projects include:

- lower cost of a project during its whole life cycle;
- faster construction phase;
- higher quality of the project and its result;
- more efficient design, construction and operating phases – better safety during the whole project life cycle, fewer errors;
- controlled whole-life costs and environmental data – environmental performance is more predictable, lifecycle costs are better understood;
- better ways to manage risk (Matějka & Tomek, 2014, p. 505).

BIM is used throughout the life cycle of a project and can integrate information from multiple areas of project management: design, current conditions modelling, budgeting, scheduling, digital fabrication, site design and analysis, project review (Matějka & Tomek, 2014, p. 502). According to Fischer & Hartmann (2008), the main hurdle that the construction industry needs to overcome is integration of BIM across different stages and various stakeholders of a project. One of the important areas of the integration of management and decision-making processes related to the design and implementation of a construction project is risk management and integrated change control.

Risk management in BIM projects

Risk described in publications related to BIM is usually referred to as the risk influenced by the use or implementation of BIM, or the risk inherent in BIM perceived as its risk source (Chien, Wu & Huang, 2014; Matějka & Tomek, 2014, p. 506). Publications discussing the problem of risk in BIM projects typically involve a fragmented aspect of risk management, limiting the considerations to the risk of fire or safety issues, among others (Schatz & Ruppel, 2014; Esmaeili & Hallowell, 2012).

Eastman *et al.* (2011) report a case of the use of BIM in safety planning and management. The example concerns a steel frame building in Yas Island, Abu Dhabi, where cylinders were used to model the spaces occupied by the activities of welding crews. Clash detection between cylinders was then used to identify possible exposures of workers to dangers posed by other teams from time to time. Kiviniemi *et al.* (2011) describe the use of BIM for the following safety-related activities: site layout and anti-crane collapse plan, wall demolition visualization, safety railing modelling, formwork plan with integrated fall protection and design for safety model checking. They state that BIM-based safety demonstrations are an effective tool for discussing and communicating safety-related issues at the jobsite with project managers, site superintendents and workers. Collins *et al.* (2014) share the results of a study of the levels of safety risk at each stage of a scaffoldings project life cycle for building a masonry wall and how these risks and related mitigation suggestions can be applied to Building Information Models (BIM). Four different stages of research were conducted to determine the safety risks and then implement the mitigations into BIM. Safety was integrated with 4D BIM by linking the scaffolding safety risks and mitigations with the project schedule. Based on the findings, the authors conclude that 4D BIM can be used as a tool for safety management to monitor and diminish safety hazards associated with the scaffolding work.

On the other hand, Patrick & Issa (2007) indicate that the assessment of perceptions about the impact of the implementation of BIM on construction projects showed that only 46% of the respondents thought that construction safety was improved through BIM. According to authors, such limitations are caused by incomplete BIM data, especially the lack of safety analysis information.

Another area of the analysis related to risk management in BIM projects is collision detection at the design stage of a project life cycle. A comparative analysis of several case studies conducted by Giel & Issa (2013) shows that the implementation of BIM resulted in a 37% reduction in change orders and the total cost of change orders on the BIM-assisted project totalled roughly 10% of that of a similar project constructed without BIM. LeFevre (2011) also indicates that direct collision detection savings in BIM projects are the main advantage of BIM in the area of risk management.

Some authors, however, point to the risk resulting from the implementation of BIM. Mitchell (2011) argues that a logical consequence of integrated project delivery is its impact on risk management, among others, seen as a significant impediment to the adoption of BIM. Matějka & Tomek (2014) cite numerous authors who perceive the risks inherent in BIM as their risk source. Azhar, Hein & Sketo (2012) claim that the concept of BIM blurs the level of responsibility so much that risk and liability will likely be enhanced. Contractual issues such as risk allocation, compensation, insurance and dispute resolution common in traditional contract documents cannot be easily dealt with in BIM projects (Abanda *et al.*, 2013). In this regard, a survey of Pishdad & Beliveau (2010) suggests that the development of a Multi-Party Contracting Risk Management model will allow the potential contracting parties to a BIM project to share their insights about the existing risk, collaboratively develop the most effective risk management strategies, and to negotiate contract terms accordingly.

As the issue of integrated risk management in BIM projects has not been sufficiently studied and described so far, in the author's opinion, it is an interesting area for exploration. First of all, the study concerns the methodical integration of risk and change management in BIM projects. The implementation of BIM is a difficult process that requires genuine cooperation and integration of many sub-sectors and work systems. Assuming that BIM presents a holistic approach to the management of the entire construction project at its every stage, the investor, the authors of project documentation, clerks of works, construction workers and project supervisors should all be aware of the importance of risk management and have a methodical approach to this issue.

The World Trade Center (WTC) reconstruction project in the City of New York is an example of a project carried out according to the objectives of BIM and attempting to integrate risk management activities. The process of integration of risk management issues with the project management based on BIM technology has been described by Harvey *et al.* (2009). The project involves land development of about 16 acres. The buildings include office and retail space, and facilities used to perform functions related to culture and the arts (monument, museum, performance art centre). The platform of collaboration and risk management in this project was established and then was used based on object models developed in 3-D and 4-D technologies, which are the core of BIM implementation. Its creation was launched by The Lower Manhattan Construction Command Center (the LMCCC), established by the authorities of New York in 2004. The first step taken by LMCCC was the creation of the Construction Coordination Room in order to bring all stakeholders to the table to identify and assess risk in the whole project. In other words, communication procedures between participants in the entire project were first developed. It was a very large group of stakeholders, since the scope of the WTC reconstruction includes sub-projects carried out by various investors, each of whom separately employs architects and contractors. Hence the systematization of communication between all these actors was a challenge for LMCCC and at the same time the condition for the extension of BIM into a truly integrated practice for risk management. The LMCCC managers developed the Risk Management Process to continuously track project risk, mitigation plans and decisions required to avoid schedule delays. There was a two-week Value Risk-Based Planning workshop attended by twenty-two experts. The aim of the workshop was primarily to analyse the whole project, its scope, timeframe, plans concerning logistics and construction work, as well as the relationship between sub-projects in terms of risk identification and assessment. Next, the participants developed risk response scenarios, integrating diversified perception of risk and various aims of investors, contractors and other participants. Another goal of LMCCC was to create a tool that would integrate object models developed under various sub-projects with the entire project schedule and software used to monitor the progress of the project (the site logistic and staging plans). During the subsequent risk management workshops, the entire project model was used to analyse the progress of individual projects and to compare the actual facts with the master risk model and the project schedule. The described example illustrates the assumptions of project risk management based on the core value of BIM that is coordination and visibility of the project. However, Harvey *et al.* (2009) present neither a detailed description of risk management processes in the discussed project, nor their effects, e.g., in relation to the lead time. Other examples of projects mentioned in publications on BIM are not accompanied by more extensive analysis on the actual practice of risk management in the whole life cycle of BIM projects.

CONCLUSIONS

Building Information Modelling is the subject of numerous publications describing it from different perspectives. Technological capabilities supporting design processes through the creation of 3-D, 4-D and even 5-D models are most commonly reported. Attention is also paid to benefits, primarily of economic nature, arising from the implementation of BIM assumptions in the design and implementation of investment and construction projects and then operation of the facilities and infrastructure. While the concept of BIM has been known and practiced in Western Europe for a long time, it is still an innovation in the construction industry in Central and Eastern Europe.

According to the author, risk management in BIM projects is the particularly interesting and important issue, both from a practical point of view and for the development of the theory of project management. In the publications describing BIM, the issue of risk is recognized primarily in the context of the implementation of BIM as an organizational innovation, treated as a source of risk. It is also indicated that BIM improves risk control measures, particularly in relation to project change control and safety issues. In contrast, there is no in-depth analysis of a systematic integration of different areas of project management within the BIM process, including procedures, methods and techniques of risk management. This article, based on a review of publications and research results, sets a direction for further research of the use of BIM in broad terms, as a platform for integrating key areas of construction project management, including communication and risk management. The modelling of buildings using modern, innovative information technologies is a significant transformation in the practice of design and execution of construction projects. These innovative tools are only useful in so far as they assist within the larger context of integrated communication, risk and change management. Such issues were not thoroughly addressed in the present studies. Incorporating them into subsequent research might be helpful in creating a further theoretical basis for innovative risk management in construction projects.

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BUILDING INFORMATION MODELLING – INNOWACYJNE ZARZĄDZANIE RYZYKIEM W PRZEDSIĘWZIĘCIACH BUDOWLANYCH

Abstrakt

Tło badań. Building Information Modelling to od pewnego czasu jeden z najczęściej podejmowanych tematów publikacji związanych z innowacyjnymi zmianami w zarządzaniu przedsięwzięciami budowlanymi. Ideą BIM jest integracja działań związanych z przygotowaniem, realizacją i eksploatacją obiektów budowlanych na podstawie platformy komunikacyjnej, jaką tworzy model obiektu opracowywany w technologii informatycznej. Obszarem interesującym, zarówno z punktu widzenia teorii zarządzania projektami, jak i praktyki inwestycyjno-budowlanej, jest zintegrowane zarządzanie ryzykiem i zmianą w ujęciu BIM. Negatywne konsekwencje w postaci opóźnień i strat finansowych, dotkliwe dla inwestora szczególnie w projektach publicznych, prowadzą do pytania, czy i w jaki sposób zarządzanie przedsięwzięciami budowlanymi według założeń BIM może usprawniać działania zarządcze związane z ryzykiem w tych przedsięwzięciach.

Cele badań. Celem artykułu jest przedstawienie aktualnego stanu wiedzy na temat ryzyka i zarządzania zmianą w przedsięwzięciach budowlanych w kontekście wdrażania koncepcji BIM oraz ustalenie kierunku dalszych badań związanych z tym zagadnieniem.

Metodyka. Argumentacja przedstawiona w artykule opiera się na analizie literatury przedmiotu.

Kluczowe wnioski. Ryzyko pozostaje kwestią wymagającą usystematyzowania w koncepcji BIM, konieczne są badania w celu ustalenia optymalnego sposobu integracji procedur, metod i technik zarządzania ryzykiem z pozostałymi obszarami działań zarządczych w ramach BIM. Włączenie w ten system procesów zarządzania zmianą, postrzeganą jako jeden z głównych czynników ryzyka, również wymaga ustalenia standardów i metodycznego podejścia w ramach BIM. Dalsze badania w tym zakresie powinny objąć dotychczasowe doświadczenia we wdrażaniu BIM w przedsięwzięciach budowlanych i obecność procedur związanych z ryzykiem w tym procesie oraz uwarunkowania efektywnej integracji działań zarządczych. Z praktycznego punktu widzenia istotnym przedmiotem dalszych badań jest także gotowość przedsiębiorców i inwestorów do wdrożenia BIM, rozumianego jako platforma komunikacji, zarządzania ryzykiem i zmianą, oraz optymalny sposób usystematyzowanego przeprowadzenia takiego procesu.

Słowa kluczowe: zarządzanie ryzykiem, przedsięwzięcia budowlane, Building Information Modelling